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DESCRIPTION

METHOD OF, AND APPARATUS FOR, OPERATING A RADIO SYSTEM

Technical Field

The present invention relates to a method of, and apparatus for, operating a radio system. More particularly the present invention relates to improved parameter estimation in radio systems such as communications systems, for example cellular telephone systems, ranging systems including positioning systems having multiple antennas, MIMO systems, systems for determining distances between base stations having multiple antennas and any of the foregoing embodied in mobile receivers.

Background Art

In a multipath environment, a transmitted radio signal is reflected from reflecting surfaces and is received at a receiver by way of more than one propagation path. Two of the characteristics of multipath are (1) a multipath will always arrive after the direct path signal (or line of sight (LOS) signal) because it must travel a longer propagation path, and (2) the multipath signal will normally be weaker than the direct path signal since some of the signal power will be lost from the reflection. The multipath signal can be stronger if the direct path signal is hindered in some way.

The various components or parameters of the signal received by way of different paths have different amplitudes (a_n), phases (θ_n) and delays (τ_n), which can make the information extracted from the composite received signal unreliable. For example, if the signal conveys data, the data error rate can be degraded, especially for high bit rate transmission, and if the signal is used for range estimation, the accuracy of the range estimate can be degraded. If the multipath properties of the radio signal can be characterised, the detrimental effects of multipath propagation can be reduced, for example by cancelling out unwanted reflections or by combining the signal received via different paths in a constructive manner. Also there are systems that use multi-element antennas (MEA) to achieve very high bit rate transmission. Such systems

employ a characterisation of the multipath properties of the radio signal. An MEA system is described in "Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multi-Element Antennas", G.J. Foschini, Bell Systems Technical Journal, Autumn 1996, pp. 41-59.

One approach to characterising multipath propagation is the use of parameter estimation techniques such as the Multipath Estimating Delay-Lock Loop (MEDLL) (see, for example, "Performance Evaluation of the Multipath Estimating Delay Lock Loop", B. Townsend, D.J.R. van Nee, P. Fenton, and K. Van Dierendonck, Proceedings of the Institute of Navigation National Technical Meeting, Anaheim, California, Jan. 18-20, 1995, pp. 227-283) and the Minimum-Mean-Square-Estimator (MMSE) (see, for example, "Conquering Multipath: The GPS Accuracy Battle", L.R. Weill, GPS World, April 1997). In parameter estimation techniques, the received signal is represented by a mathematical model, for example a model that includes variable parameters representing the amplitude (a_n), phase (θ_n) and delay (τ_n) of the signal components received via a plurality of propagation paths, and the parameter values are adjusted iteratively until a good match is obtained between the received signal and the mathematical model.

Reference is also made to "Multipath Channel Characteristics Using Spectral Analysis of the Signal Power Density", S. Zeilinger, T. Talty, Michael Chrysochoos, IEEE Transactions on Broadcasting, Vol.44, No.4, December 1998, Pages 527 to 539, which discusses a concept to quantify the indirect signals in a multipath environment. The article discloses that by measuring the power density over time in a multipath environment of a moving vehicle and then calculating the Fourier transform of the power density one can determine the number of reflections and the reflection coefficient for each reflection under certain assumptions. For the technique to work the path difference between the direct and the indirect field must be linear over the time period the data is collected and the Doppler shifted radial frequency-time product must also be linear over the sampled data duration.

Generally techniques for characterising multipath propagation require a great many parameters and are therefore inefficient or inaccurate.

Disclosure of Invention

It is an object of the present invention to improve on the estimation of parameters to be used in any parameter estimation technique, for example MMSE and MEDLL.

According to a first aspect of the present invention there is provided a method of operating a radio system comprising first and second stations, the method comprising the first station transmitting a signal, the second station receiving the transmitted signal at a plurality of spaced locations, analysing the received signal by frequency domain analysis to calculate the number of specular reflections and the reflection coefficient for each specular reflection, one of the first and second stations transmitting and receiving a radar signal, said one station scaling the received radar signal to appear as if it had been transmitted by the other of the first and second stations, analysing the scaled signal to determine bounds for at least one parameter of the specular reflections, utilising the results of the analysis of the radar signal at the second station to reduce the bounds on the at least one parameter by matching the specular reflection from the frequency domain analysis and the scaled radar signal, and optimising a parameter model of the received signal using the reduced bounds on the at least one parameter and the number of reflections identified in the frequency domain analysis.

According to a second aspect of the present invention there is provided a radio system comprising first and second stations, the first station having means for transmitting a signal, the second station having means for receiving the transmitted signal at a plurality of spaced locations, means for analysing the received signal by frequency domain analysis to calculate the number of specular reflections and the reflection coefficient for each specular reflection, one of the first and second stations having means for transmitting and receiving a radar signal, said one station scaling the received radar signal to appear as if it had been transmitted by the other of the first and second stations, the second station having means for analysing the scaled signal to

determine bounds for at least one parameter of the specular reflections, means for utilising the results of the analysis of the radar signal at the second station to reduce the bounds on the at least one parameter by matching the specular reflection from the frequency domain analysis and the scaled radar signal, and means for optimising a parameter model of the received signal using the reduced bounds on the at least one parameter and the number of reflections identified in the frequency domain analysis.

In the method in accordance with the present invention by using spectral analysis in combination with back scatter information, it is possible to achieve improved algorithmic accuracy and efficiency of a parameter estimation technique for multipath modelling and mitigation. By having prior estimates of parameters, characterising multipath using say MEDLL or MMSE is able to work faster and thus be able to include more parameters for greater accuracy and thereby lead to obtaining a correct solution to the non-linear problem set by MEDLL or MMSE.

Brief Description of Drawings

The present invention will now be described, by way of example, with reference to the accompanying drawings, wherein:

Figure 1 is a block schematic diagram of a radio system in a multipath environment,

Figure 2 is a flow chart relating to the operations of a radio station in the system shown in Figure 1,

Figure 3 is a diagram illustrating the geometry of the multipath scenario of Figure 1,

Figure 4 is a graph of distance versus power in respect of the signals received at the equally spaced antennas 24A to 24D in Figure 1, and

Figure 5 is a graph of frequency versus power showing non-zero spectral peaks.

In the drawings the same reference numerals have been used to indicate corresponding features.

Modes for Carrying Out the Invention

For convenience of description, the present invention will be described with reference to MEDLL.

According to MEDLL the received signals *r(t)* at the input of a receiver can be written:

$$r(t)=\sum_{n}^{M}a_n e^{j\theta_n}s(t-\tau_n)+n(t) \qquad (1)$$

where a_n is amplitude,

θ_n is phase,

τ_n is time delay,

s(t) is the transmitted signal,

n(t) is noise and

M is the total number of specular reflections.

The present invention has particular, but not exclusive, application to using better initial estimates of amplitude (a_n) and the number (M) of multipath components to improve the accuracy of estimation of all the parameters as well as speeding up the process.

In equation (1), the terms a_n, θ_n and τ_n can be determined by minimising the noise term *n(t)*.

In a situation of receiving data *D(t)* then in accordance with the MEDLL if the noise term is a random variable with the non-zero Gaussian distribution then $\sum_t n(t)=0$.

As a result, the mean square error between the signal components and the received signal is:

$$\sum_t\left[D(t)-\sum_{n=0}^{M}a_n e^{j\theta_n}s(t-\tau_n)\right]^2=\sum_t[n(t)]^2=0 \qquad (2)$$

By minimising this expression one has a non-linear problem giving non-unique solutions.

By having prior estimates of the parameters a_n, θ_n and τ_n, characterising the multipath components according to the MEDLL or MMSE will be faster and thus be able to include more parameter values for greater

accuracy, and is more likely to find the correct solution to the non-linear problem.

Referring to the radio system of Figure 1, a first radio station 10 comprising a first transceiver 12 is coupled to a first antenna 14 and to a first processing means 16. A storage means 18 is coupled to the first processing means 16 for the temporary storage of data. A second station 20 comprising a second transceiver 22 is coupled to a plurality, for example four, equally spaced second antennas 24A to 24D. A second processing means 26 is coupled to the second transceiver 22 and a second storage means 28 is coupled to the second processing means 26 for the temporary storage of data. Both transceivers 12, 22 are equipped to communicate using spread spectrum signalling. Also illustrated in Figure 1 are first and second reflecting surfaces 40, 50 which may be, for example, walls having the same or different reflection coefficients. In a practical scenario there may be more reflecting surfaces but for clarity only two are illustrated in Figure 1.

In operation the first station 10 transmits an omnidirectional signal. Back scatter S1 and S2 reflected from the reflecting surfaces 40, 50 back to the antenna 12 are retained and are used by the first processing means to determine the position of the first station relative to the reflecting surfaces 40, 50, viz. the distances $d_{b1}/2$, $d_{b2}/2$, and the first processing means 16 includes this positional information in the omnidirectional signals. If the first station is fixed then it will not be necessary to repeatedly determine its relative position. At the second station 20, the omnidirectional signals, which may be the subject of multipath or specular reflection, are received by the antennas 24A to 24D. For convenience of illustration a line-of-sight (LOS) signal 42 and two reflected or multipath signals 44, 46 are shown.

The second processing means 26 computes the range by means of a suitable technique, such as a range estimating equation such as MEDLL. The method in accordance with the present invention relates to an improved estimation of these and other parameter values.

The flow chart shown in Figure 2 summarises the method in accordance with the present invention. The method provides an algorithm for improved

multipath estimation by at least employing spectral analysis of the signal power density for a mobile receiver or multiple antenna system. This determines the number of specular reflections along with the value of the respective reflection coefficients. The algorithm uses the power density information at each antenna of the multi-antenna receiver together with the radar (or sounding) signal derived from the back scatter S1 and S2 in order to improve the efficiency or accuracy of parameter estimation of the multipath signals. The technique processes instantaneous information of the environment to aid any system that requires knowledge of the channel.

Referring to Figure 2, block 60 relates to the first transceiver 12 transmitting an omnidirectional signal. Block 62 relates to the first station 10 receiving and retaining the radar (or sounding) information in the back-scatter S1, S2, estimating the distances d_{b1} and d_{b2} (Figure 1) and including this distance information in a subsequent omnidirectional signal for use in the computations done by the second processing means 26 in the second station 20. Block 64 relates to the multipath reflected by the surfaces 40, 50 being scaled by a process to be described later. Block 66 relates to the second processing means determining bounds for the amplitude a_n and delays τ_n of the reflected multipath from the scaled back-scatter.

Block 68 relates to the multiple antennas 24A to 24D receiving the direct line of sight signal and the reflected multipath and the second processing means 26 computing a power versus distance profile. Block 70 relates to the power-distance profile at each antenna being transformed using for example Fourier transforms to the spatial-frequency domain. Block 72 relates to examining the transformed profile for delta functions (otherwise termed the peaks) occurring at non-zero frequencies due to the specular reflections. Block 74 relates to deriving the reflection coefficients of the specular reflections from the power (or height) of the delta functions and the total number M (Equations 1 and 2) of specular reflections from the total number of delta functions.

Block 76 relates to matching the reflection coefficients bounds found by way of back scatter and their delays (block 66) with those from the spectral

analysis of the power versus spatial frequency domain. Block 78 relates to reducing the amplitude bounds to more accurate numerical values for the amplitudes which are matched with their respective delay bounds. The total number of specular reflections or delta functions is known from the block 74 and can be used in parameter estimation. Block 80 relates deriving a diffuse background function from the total number of specular reflections and adding it to the computations at the correct juncture.

Block 82 relates to an option of using a selected one of the antennas 24A to 24D to transmit a radar (or sounding) signal. The flow chart thereafter proceeds to the block 62.

Referring to Figure 3 which shows an omnidirectional ranging signal transmitted by the second station 20 and received in the form of a direct signal and multipath (or specular reflections) by the first station and a radar signal transmitted laterally by the station 10 to the reflecting surfaces 40, 50. The length of the direct (or LOS) path is d_0 and the lengths of two reflected paths are d_1, that is $(d_{1A} + d_{1B})$, and d_2, that is (d_{2A} and d_{2B}). The lengths of the radar (or sounding) paths S1 and S2 is half their respective round trip distances $d_{b1}/2$ and $d_{b2}/2$. The angles of arrival of the LOS path d_0 and a line perpendicular to the reflecting surface are φ_1 and φ_2, respectively.

From Figure 3 it can be deduced that:

$$d_1 = d_{1A} + d_{1B} = \sqrt{d_0^2 + 4 d_0 d_{b_1} \cos\varphi_1 + d_{b1}^2}$$

$$d_2 = d_{2A} + d_{2B} = \sqrt{d_0^2 + 4 d_0 d_{b_2} \cos\varphi_2 + d_{b_2}^2}$$

These equations can be generalised so that the distance d_k can be expressed by the equation:

$$d_k = \sqrt{d_0^2 + d_0 d_{b_k} \cos\varphi_k + d_{b_k}^2}, \text{ for } k > 0 \qquad (3)$$

where φ_k is the angle of arrival of the signal received via the direct path and d_0 is the direct path distance. The angle of arrival φ_k is defined as the angle

between the direct path and a line perpendicular to the *kth* reflecting surface, such that the angle is not intersected by the *kth* reflected path, as shown in Figure 3.

The model of the received back scatter of the radar (or sounding) signal correlation function is scaled in time and amplitude, by the first processing means 16, to approximate the reflected signal that would be received if the radar (or sounding) signal had been transmitted from the second station 20. In order to scale in time, each d_{b_k} in equation (3) is replaced by the distance d_k travelled if the signal contributing to that sample had travelled from the second station 20 via a surface having the same reflection coefficient. Analysis of the multipath geometry illustrated in Figure 3 shows that the distance d_k travelled by a signal transmitted by the second station 20 and received at the radio station 10 via a *kth* reflecting surface can be expressed as

$$d_k = \sqrt{d_0^2 + d_0 d_{b_k} \cos\varphi_k + d_{b_k}^2} \quad \text{for } k > 0 \qquad (4)$$

In order to scale the amplitude, each sample amplitude a_{b_k} is replaced by the amplitude a_k that the sample would have if the signal had travelled from the second station 20 via a surface having the same reflection coefficient. Using the generally accepted inverse fourth power law for the attenuation with distance travelled, a_{b_k} can be represented as

$$a_{b_k} = \frac{B\mu_k}{{d_{b_k}}^2} \quad \text{for } k>0 \qquad (5)$$

where B is the amplitude of the transmitted back scatter signal and μ_k is the reflection coefficient of the reflecting surface, and a_k can be represented as

$$a_k = \frac{A\mu_k}{d_k^2} \quad \text{for } k>0 \qquad (6)$$

where A is the amplitude of transmissions from the second station 20.

Combining equations (3), (5) and (6) gives

$$a_k = \frac{A a_{b_k} d_{b_k}^2}{B\left(d_0^2 + d_0 d_{b_k} \cos\varphi_k + {d_{b_k}}^2\right)} \quad \text{for } k>0 \qquad (7)$$

Replacing d_{b_k} in equation (3) by the expression of equation (5), and a_{b_k} in equation (5) by the expression of equation (6) gives the following expression for the scaled model of the received radar (or sounding) correlation function, i.e. a model representing a signal transmitted by the second station 20 and received at the first station 10:

$$R_{b\,scaled}(\tau)=\sum_{k=1}^{K}\frac{A\,a_{b_k}d_{b_k}^2}{B\left(d_0^2+d_0\,d_{b_k}\cos\varphi_k+d_{b_k}^2\right)}F_b\left(\frac{\sqrt{d_0^2+d_0\,d_{b_k}\cos\varphi_k+d_{d_{b_k}}^2}}{c}\right) \quad (8)$$

$R_{b_{scaled}}(\tau)$ comprises measured data, referred to as radar (or sounding) data, derived from the received back scatter signal and some parameters having unknown values,

$F_b(\tau_k)$ is the correlation peak with the peak centred at τ_k and width $2T_c$ (that is double chip width).

A numerical example will now be given with a view to facilitating a greater understanding of the method in accordance with the present invention. Figure 4 is a graph of power (ordinate) versus distance (abscissa) of the back scatter received by the antennas 24A to 24D (Figure 1). Figure 5 shows the Fourier Transform of power versus distance graph shown in Figure 4 to obtain the power density spectrum in k-space and illustrates non-zero frequency spectral peaks.

D(t) is the received signal data.

$\sum_t D(t)s(t-\tau)=K(t)$ is the received correlation function.

To obtain initial estimates of parameters:

$K(\tau)=F_b scaled(\tau)+a_o e^{j\theta_o}F_b(\tau_0)$

where $K(\tau)$ is ranging data.

This equation is solved for d_0 and φ_K, a_0 and θ_0.

From d_0 and φ_k we obtain a_k and d_k from equations (7) and (4) above.

So from scaled back scatter we obtain initial estimates of a_0, θ_0, d_0, φ_k, a_k and d_k for all components.

Examining the spectral peaks shown in Figure 5, values for amplitudes $a_1,\ldots a_n$ can be obtained. The amplitudes are matched and the more accurate amplitude value derived from the spectral analysis is used in eliminating multipath from the received signal to get the line of sight (LOS) signal from which a range estimation can be made.

Although the embodiment shown in Figure 1 shows the second station 20 having a plurality of equally spaced antennas, it is not essential for them to be equally spaced. An alternative possibility would be for the second station 20 to have one antenna and move at a constant speed and the received signal being sampled spatially at equal time increments. Further it is not essential for the signal propagated by the station 10 to be omnidirectional.

Reference is made to International Patent Applications IB 02/02734 (Applicant's reference PHGB 010139) which relates to accurate range and angle of arrival measurement from dominant reflection information and IB 02/02735 (Applicant's reference PHGB 010140) which relates to accurate range and angle of arrival measurement from scaled back-scatter data, details of which patent applications are incorporated into the present application by way of reference.

In the present specification and claims the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. Further, the word "comprising" does not exclude the presence of other elements or steps than those listed.

From reading the present disclosure, other modifications will be apparent to persons skilled in the art. Such modifications may involve other features which are already known in the design, manufacture and use of radio ranging systems and component parts therefor and which may be used instead of or in addition to features already described herein.

<u>Industrial Applicability</u>

The present invention relates to improved parameter estimation for use for use in radio systems such as communications systems, for example

cellular telephone systems, ranging systems including positioning systems having multiple antennas, MIMO systems, and systems for determining distances between base stations having multiple antennas.